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AN EXPERIMENTAL DEMONSTRATION OF HIGH-RESOLUTION DOPPLER PROCESSING

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13. ABSTRACT (Maximum 200 words)

This correspondence reports the experimental results of applying the Coherent Wideband MFBLP to processing of the radar data obtained in a real target-clutter environment for the resolution improvement in the doppler frequency domain. Significant resolution improvement is obtained and further research topics are suggested.

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I. INTRODUCTION

High resolution spectrum estimation and its applications have been an active research topic for many years, especially in the ASSP society. Many theoretical results have been obtained (such as those summarized in [1]-[3]), and its applications to various practically important problems have started to receive more attention.

One of the possible applications is to improve the resolution in the Doppler frequency domain of a pulse radar system for better detection of moving targets in clutter. Since the suggestion was made in the early stage of high resolution spectrum estimation [4], some concerns have been raised about its feasibility. Ref. [5] questions the validity of the pointwise-target assumption (which is critical to the formulation of the familiar problem of "multitone in noise") and the effects of imperfect equipment and inadequate signal-to-noise/clutter ratio. In a rather lively argument [6], White emphasized on his observation that the tone resolution performance of MEM and MLM is sensitive to the phase difference between the tones which makes the resolution improvement unreliable. These "negative" comments may have discouraged some of further research on applying high resolution spectrum estimation to the doppler resolution problem.

This paper reports on experimental demonstration of significantly improved Doppler resolution in a *real* target and clutter environment which is based on the theoretical study of [7] and [8]. In addition, some further theoretical research topics are suggested from our observation and interpretation of the experimental results.

II. THEORETICAL BASIS AND EXPERIMENT DESIGN

In [7] and [8], the high-resolution performance sensitivity is examined as a parameter estimation problem. The main results of that study relevant to this paper is summarized below for convenience:

1. it is necessary to use a multiband (frequency diversity) system for data acquisition if one wants to obtain a high- resolution performance in the Doppler frequency domain

insensitive to the practically uncontrollable phase differences among the tones to be resolved, especially in the cases of short- time observation;

2. the number of subbands required to do so is small; and

3. a coherent high-resolution method should be used to process the multiband data rather than a noncoherent one such as the postaverage of the spectral estimates.

Our experiment was designed with the above theoretical guidance. We note that Ref. [9] arrives at the similar conclusions for angle-of-arrival resolution in multipath.

We agree that targets of interest are rarely pointwise in practical situations. To our knowledge, there is no theoretical result available on the effects of non-pointwise targets on high resolution performance in the Doppler frequency domain. In fact, we feel that theoretical studies of this topic may well benefit from starting on careful modeling of experimental data.

The system we used for data acquisition is an L-band radar located at the Surveillance Laboratory of Rome Air Development Center. The system parameters and specifications relevant to for this experiment are given below, and the details can be found in [10].

Signaling Waveform

The transmitted waveform is the so-called *intra-pulse frequency diversity signal*. The waveform generator is programmed to produce a sequence of coherent pulses, each consisting of three subpulses whose carrier frequencies are separated by 5 MHz. Figure 1 shows one pulse with the reference frequency fixed at 9 MHz, and Fig. 2 is the corresponding spectrum. The subpulse width of three microseconds leads to a range resolution of 450 meters. We note that the 5 MHz separation of the subpulse carrier frequencies is just to assure the statistical independence among the data from different subbands [11]. This selection of the subband separation represents a relative system bandwidth, defined as the ratio of the maximum band span over its central frequency, slightly below 1 %. The pulse repetition frequency is set to have phase- coherent returns over the total observation (data acquisition) time.

A/D Conversion and Preprocessing

The in-phase and quadrature-phase receiver outputs are sampled at 13.33 MHz and digitized into 12 bits per sample. Precaution has been taken to avoid the quantization overflow. Digital filtering is then performed to separate the three subband signals followed by digital matched filtering for each subband. The 3 microsecond time-of-arrival difference between the adjacent subband outputs is removed, and a proper decimation is performed to make the final sampling interval equal to the 450 meter range resolution as determined by the subpulse waveform. A 14.4 Km range window of interest is preselected which is equivalent to 32 range cells (indices) with the 450 meter range resolution.

The data set we have now consists of three complex matrix of 8×32 each. Range distributed ground clutter and one moving target (aircraft) with a near-zero Doppler frequency exist in this data set, and the subsequent processing is to resolve them in the Doppler frequency domain. It should be noted that the moving target position change during the data acquisition is negligible.

III . Doppler Resolution Results and Discussion

The following algorithms are used to process the three data vectors at each of the 32 range indices.

1. the coherent wideband modified forward-backward linear prediction (CWB-MFBLP) [7] which is based on the ideas of [12] and [13];

2. the noncoherent wideband MFBLP which is a postaverage of the three MFBLP spectra obtained from the three subband data vectors separately;

3. the averaged Fourier spectrum estimation with the rectangular and Hamming windows which serves as a resolution performance reference.

With the first two algorithms above, the prediction filter length L is 6 which represents a good compromise between the resolution and smoothing [12]. As the existence of targets and clutter is known *a priori* in this experiment, the estimation of the number of the principal components (required by the first two algorithms) is not performed.

Figures 3 and 4 show the averaged Fourier Doppler spectra at the 32 range indices with the rectangular and Hamming windows respectively. As the Fourier resolution is only about the reciprocal of the total observation time, the weaker target of small Doppler frequency shift is not detectable in the shadow of stronger clutter centered at the zero Doppler frequency. In contrast, Fig. 5 shows the corresponding CWB-MFBLP spectra where the target is clearly detectable. Fig. 6 is for the "zoomed-in" CWB-MFBLP spectra around the target-clutter region. The "range splitting" of the target should be noted in Fig. 6 which will be discussed later in this section. The noncoherent WB-MFBLP spectra are shown in Fig. 7 where the target component fails to show up even though the clutter component is sharpened in the Doppler frequency domain.

We now turn our attention to the "range splitting" of the target component shown clearly in Fig. 6. According to the matched filter theory, the subpulse waveform used in this experiment should lead to a triangularly modulated component at the matched filter output with the length of the triangle base equal to 6 microseconds (two times the subpulse width) if the target were truly pointwise. Compared with the 450 meter range resolution, our target can only be approximately pointwise. If the range splitting is indeed caused by the finite size of the target, then it is interesting to see whether it is related to the target shape and whether the relation is useful for target identification and/or classification. Since the CWB-MFBLP spectrum represents a nonlinear transform of the data, the splitting may be caused by the interaction among the target, clutter, and receiver noise. If this is the case, its effects on the false alarm of a threshold detection should be assessed and some smoothing operation along the range index may be incorporated if necessary. To do so, a good statistical modeling of the splitting should be proposed first.

IV . CONCLUSION

This experimental demonstration shows that via the application of a proper high-resolution spectrum estimation method, Doppler resolution significantly higher than the reciprocal of the total observation time can indeed be achieved with ordinary equipment in a real target-clutter environment. Further research is necessary to deal with the observed "range splitting." It is our hope that the work reported here can help encourage the current efforts in the spectrum estimation and modeling area to push some of the "theoretically mature" results toward the application stage and to recognize new research topics while doing so.

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Figure Captions

Fig. 1 The transmitted waveform with the reference frequency at 9 MHz

Fig. 2 The spectrum of the transmitted waveform

Fig. 3 Averaged Fourier Doppler spectra (rectangular window)

Fig. 4 Averaged Fourier Doppler spectra (Hamming window)

Fig. 5 CWB-MFBLP spectra

Fig. 6 "Zoomed-in" CWB-MFBLP spectra

Fig. 7 Postaveraged MFBLP spectra

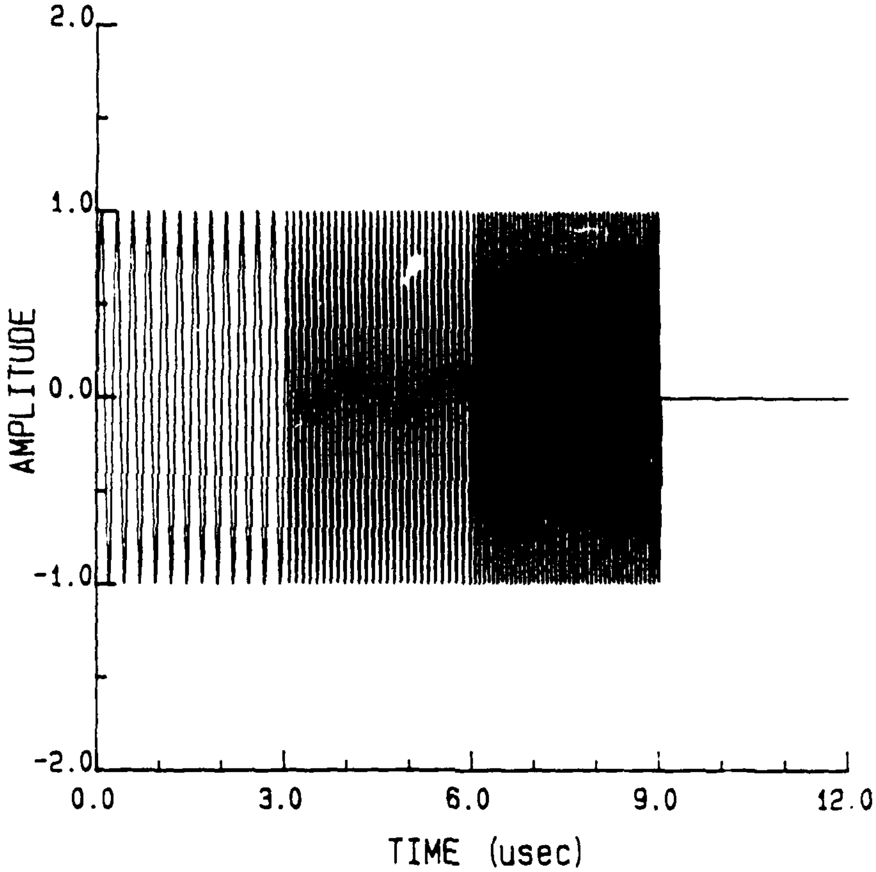


Fig. 1

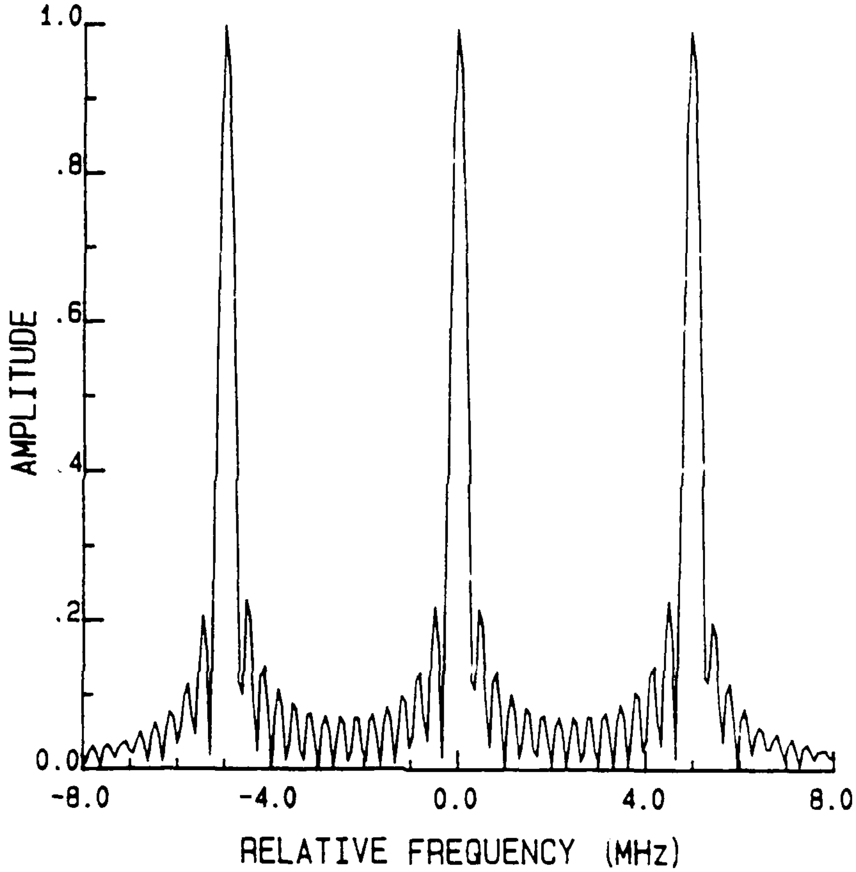


Fig. 2

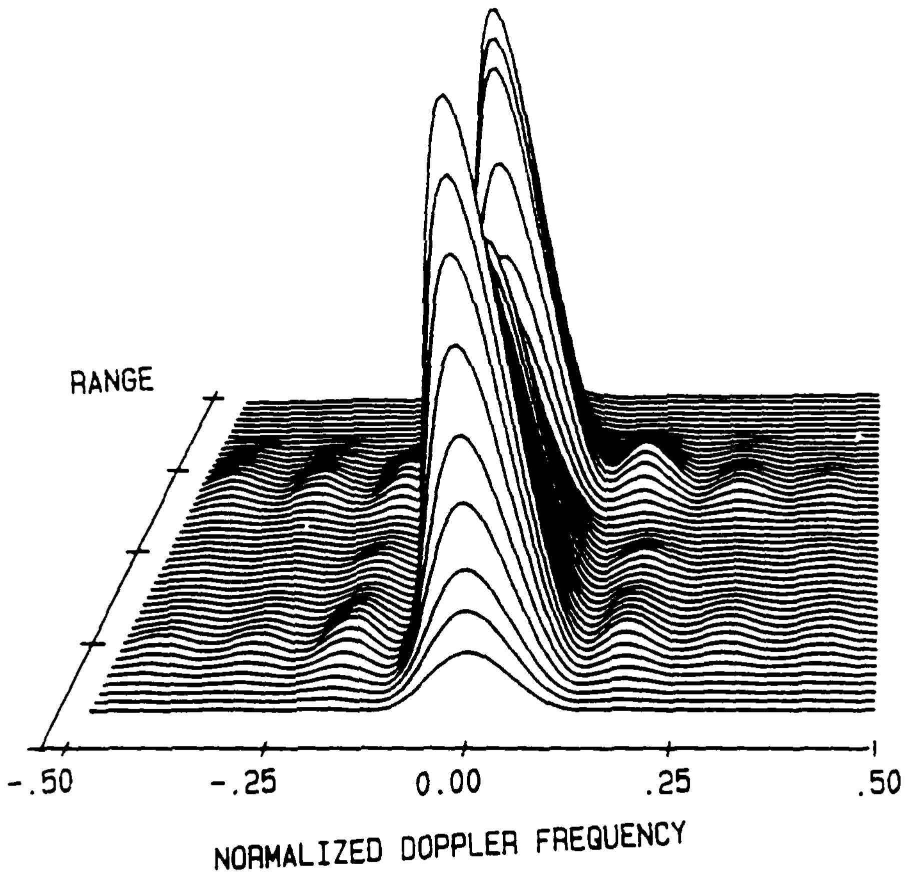
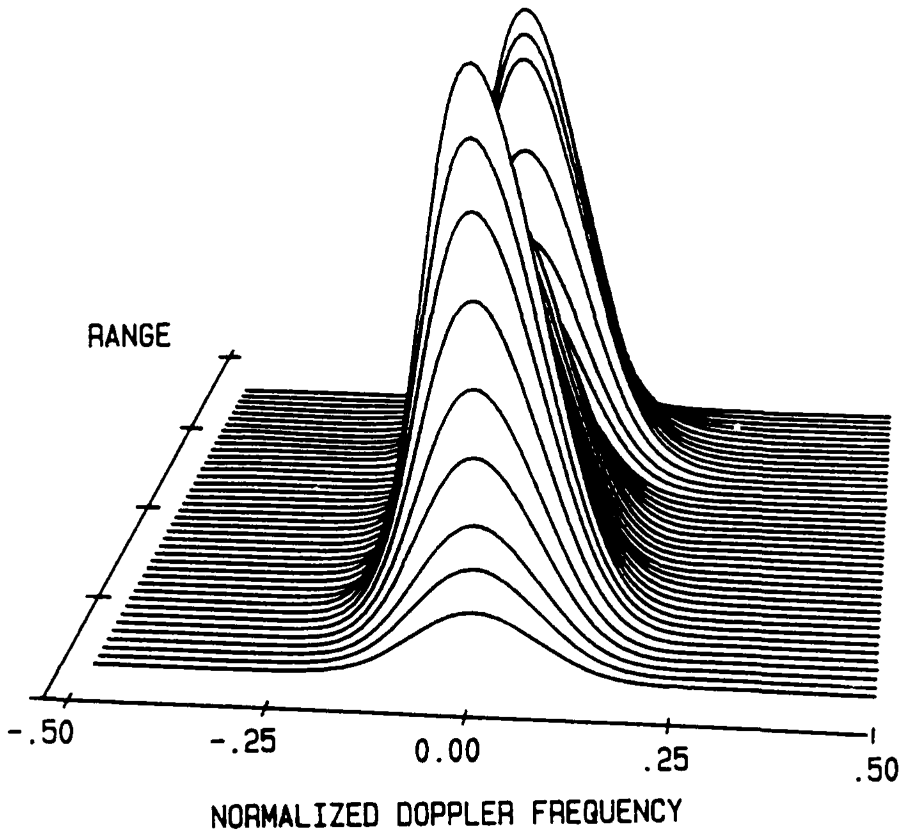


Fig. 3



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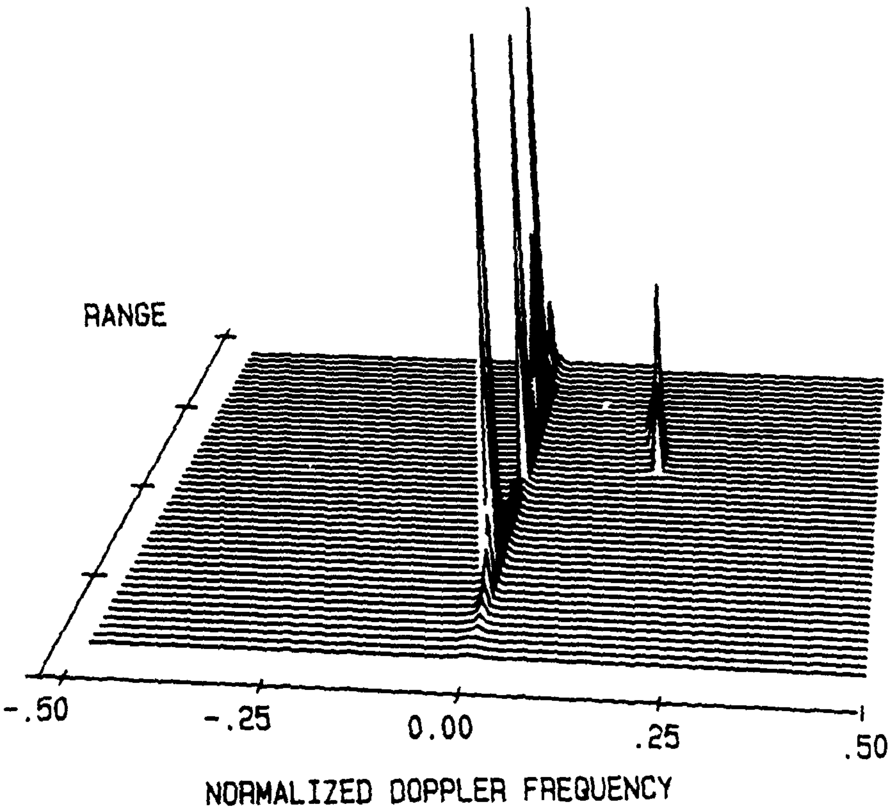

Fig. 5

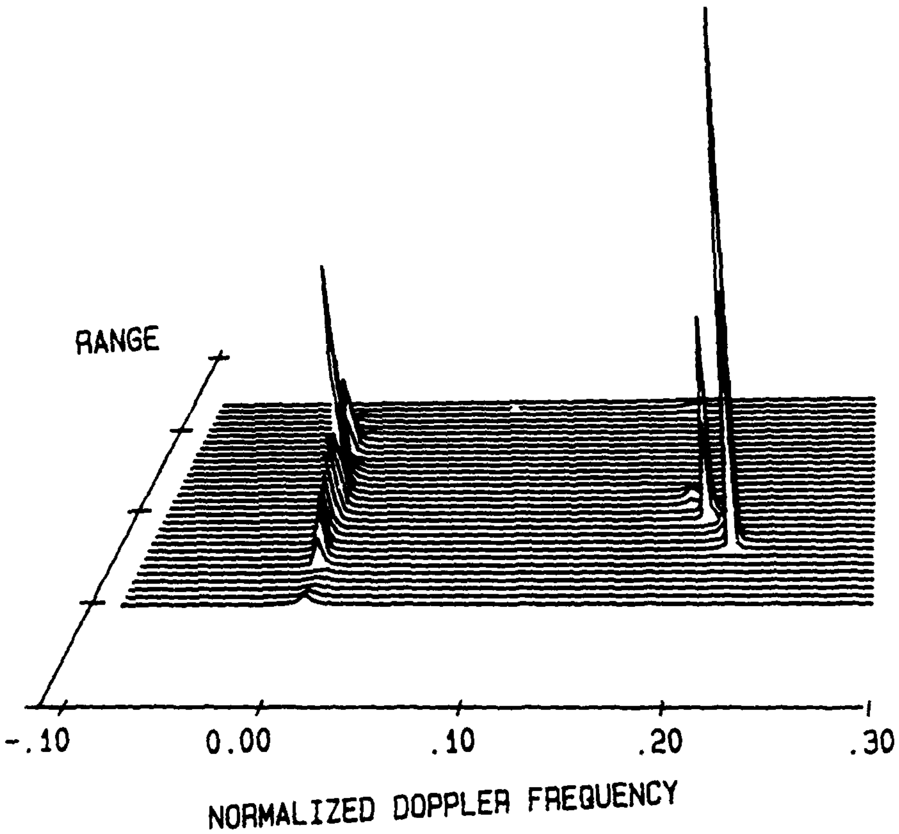

Fig. 6

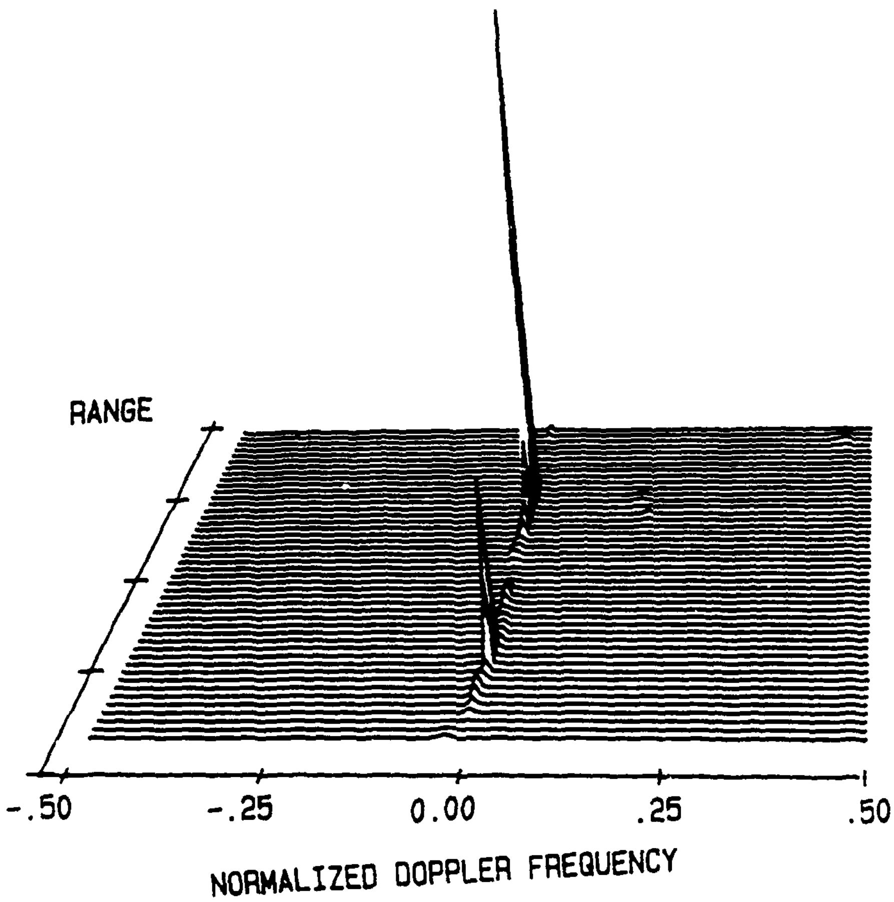

Fig. 7

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